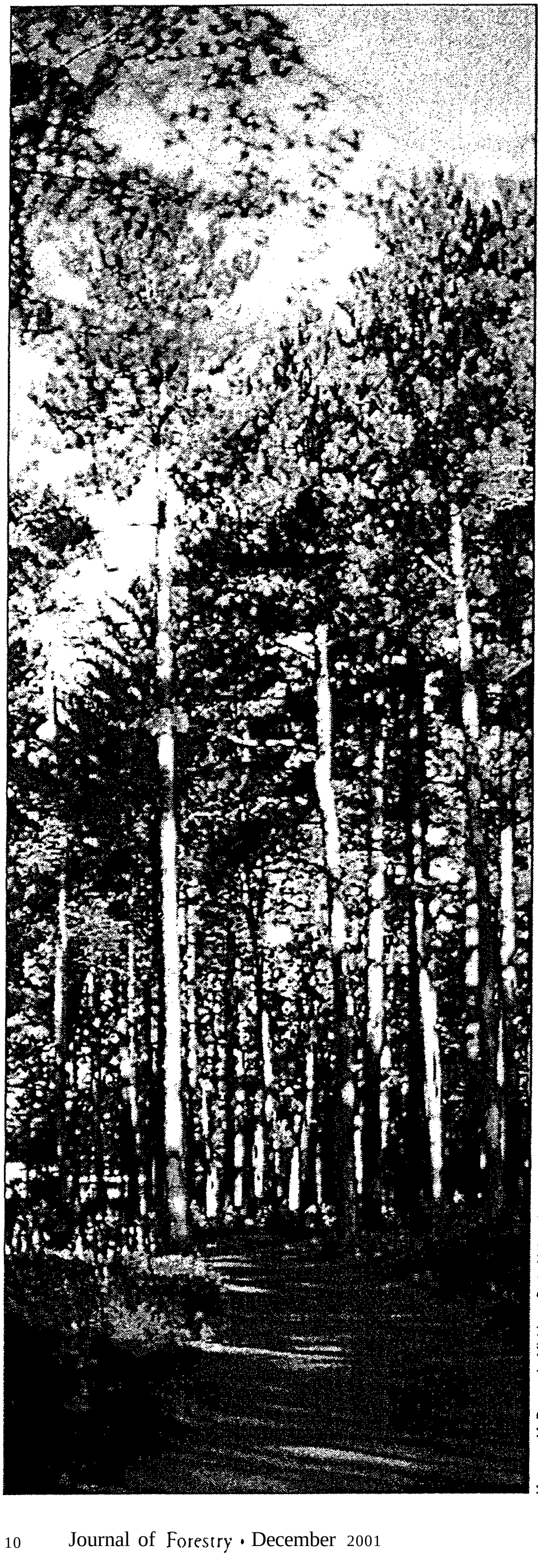

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# Is This the Age of Intensive Management?

## *A Study of Loblolly Pine on Georgia's Piedmont*

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ABSTRACT

Using data for loblolly pine from Georgia's Piedmont, we find that, although the transition from natural to artificial regeneration leads to increased and better distributed stems, the control of competing vegetation results in a dramatic boost to the growth rate from previous- to current-generation plantations. Our results indicate that the marginal returns of forest management are increasing rather than diminishing; the more intensive the management, the better its economic performance. These findings suggest that intensive management represents a major technical change and bodes well for the future of commercial forestry in the South.

Keywords: economics; herbicides; plantation forestry; silviculture

Southern pine management encompasses five major regimes-natural stands, previous- and current-generation plantarions established on cutover lands, and previous- and current-generation plantations established on old-field lands (Pienaar and Rheney 1997; USDA Forest Service 1988). A comparison of how these management regimes perform can help reveal their impact on forest investment, timber supply, and land use.

Natural srands are those regenerated after the harvest of exisring timber. Plantations can be established on harvested timberland (cutover land) or on previously cultivated (old-field) land. Most previous-generation plantations were established on cutover lands following some kind of mechanical sire preparation; current-generation plantations are es-

*Left:* Many early-generation loblolly pine plantations were established on cutover land.

tablished after mechanical or chemical site preparation. What primarily distinguishes the two generations is the current generation> effective control of competing vegetation, especially via herbicide treatment, at the time of tree planting. In addition, fertilization has been adopted extensively for current-generation plantations and, if done appropriately, can have significant positive effects (Schultz 1997; Allen in press). Because growth response from fertilization is more site-specific (Pienaar and Rheney 1997; Shiver 1998), fertilization will not be considered here.

Timber production in Georgia, as in many other southern states, is undergoing a transition from the use of natural stands to the use of planrations as the major wood producer. *Table* I **shows** that softwoods account for 44.7 percent of the 23.7 million acres of commercial timberland in the state, carrying 41 percent of the total stocking volume of 31.7 billion cubic feet. Nonetheless, softwoods contribute 67.6 percent of the annual removal and 62.7 percent of the annual growth. Among softwoods, even though 65.0 percent of the annual removal and 63.3 percent of the stocking volume still come from natural pine srands, plantation acreage increased from 31.4 percent of the total in 1382 to 57.1 percent in 1998, providing 58 of the annual growth.

Furthermore, the management inrensity of plantation forests in Georgia and other southern states has increased over the past decade. In addition to the widely practiced mechanical and chemical sire preparation and fertilizer application, thinning and even irrigation are used by landowners, particularly industrial landowners. Meanwhile, the quality of seedlings also has improved significantly (Industry Cooperative Tree Improvement Program 1993). Annual forest management activities in Georgia from 1382 to 1997 included site preparation of 230,800 acres, artificial regeneration of 308,300 acres, natural regeneration of 250,700 acres, commercial thinning of 87,600 acres, other stand improvement of 22,600 acres, and other treatment of 178,500 acres (Thompson 1998). Available statistics also suggest that, from 1386 to 1998, tree farms established on marginal agricultural lands under the Conservation Reserve Program alone amount to more than 767,000 acres in that state (USDA Farm Service Agency 1999).

Expansion and intensified management ofplantation forests have led some to predict that the South is rapidly approaching the age of intensive plantation forestry (Sedjo and Botkin 1997; Binkley 1999; Borders and Bailey 2001). It is commonly held that intensified silvicultural practices can significantly increase the productivity of plantation forests. Although there have been studies of forest productivity in response to control of competing vegetation (e.g., Miller et al. 1991; Pienaar and Shiver 1993), use of fertilizers (e.g., Stearns-Smith et al. 1992; Allen in press), and genetic improvement of planting stock (e.g., Hodge et al. 1989; Cornelius 1994), our knowledge of the advantages and disadvantages of pine management regimes is far from complete. Many of the previous studies have been limited to small-sample or short-term observations; rarely has a cross section of all the major regimes been compared and contrasted. Moreover, even if intensive management can increase forest productivity, the question remains whether this practice is financially preferable or socially acceptable.

Only if plantations of the current generation outperform those of the previous generation and plantations of the previous generation in turn outperform natural stands-both biologically and economically----can more intensive management play a major role in the future of forestry. The purpose of this article is to compare and contrast these management regimes using loblolly pine *(Pinus taeda L.)* grown in Georgia's Piedmont. Plantation regimes are further distinguished according to their origins-cutover versus old-field site. Our analysis measures the performance of these regimes in terms of their productivity, profitability, and cost advantages.

## Experimental Data and Models

The growth-and-yield models used in this analysis are from two studies by the Plantation Management Research Cooperative (PMRC) at the University of Georgia by Pien-

**Table 1. Commercial timber resources in Georgia, 1982 and 1998.**

| Forest type | Acreage (thousand acres) | Volume (million cubic feet) | Growth (million cubic feet) | . Removal (million cubic feel) |
|---|---|---|---|---|
| **Data from 1982 survey** | | | | |
| Softwoods, natural | 7,846.8 | 11,538.3 | — | — |
| Softwoods, planted | 3.592.2 | 2,403.8 | — | — |
| Total softwoods | 11,438.9 | 15,882.4 | 1.189.6 | 1.086.7 |
| Total timberland | 23,733.7 | 29,572.2 | 1,756.3 | 1,368.0 |
| **Data from 1998 survey** | | | | |
| Softwoods. natural | 4,569.8 | 7,945.9 | 409.5 | 615.1 |
| Softwoods, planted | 6,070.1 | 4,763.2 | 564.8 | 327.4 |
| Total softwoods | 10,639.8 | 12,996.3 | 974.3 | 998.0 |
| Total timberland | 23,796.1 | 31,704.0 | 1,552.8 | 1,476.7 |

*NOTE: Volume. growth. and removal statistics pertain to growing stock.*
*SOURCES: Sheffield and Knight (1984); Thompson (1998).*

aar and Rheney (1997) and Martin and Brister (1999). In collaboration with more than 15 forest products companies, the cooperative has been conducting experiments of silvicultural treatments and developing growth-and-yield models for major plantation management regimes for the past two decades. The data were collected mostly from samples of large-scale regional operations, making the resulting models more representative and reliable than those used before. In addition, the models can capture growth-and-yield shifts in response to treatment changes, enabling us to determine the effect of an added practice.

Commissioned by the Georgia Consortium for Technological Competitiveness in Pulp and Paper, Pienaar and Rheney (1397) provide perhaps the most sophisticated growth-and-yield models for previous and current generations of plantations on both cutover and old-held lands. For loblolly pine, their models fit both the Piedmont and Upper Coastal region and the Lower Coastal region. Models for loblolly pine on cutover lands in the Piedmont region (the region in our study) were derived from a designed field experiment installed in 1986. Among the site preparation treatments represented at all 25 locations were the following:

- Chop and burn-a single pass with a rolling drum chopper followed by a broadcast burn several weeks later.
- Shear, pile, and disk-using a KG blade with debris removed from the site, which was then flat-harrowed.
- Herbicide, burn, and herbicide-a herbicide treatment followed by a broadcast burn with follow-up herbicide spot spraying.

The first two methods are mechanical treatments; the third chemical. The shear, pile, and disk treatment led to only a minor yield increase compared to the basic chop and burn treatment, whereas effective control of all competing vegetation through herbicide, burn, and herbicide resulted in a dramatic increase in expected yield. Therefore, this study does not cover the mechanical site preparation methods.

Compared to the availability of reliable plantarion growth-and-yield models, models for natural stands are neither adequately available nor reliable. To address this problem, cooperative researchers established 75 circular plots of varying size (one-quarter to one-half acre) in even-aged natural loblolly pine stands in 1989. Plots were selected to cover the range and stand conditions found in Georgia's Piedmont region (Shiver and Brister 1996). These stands are typically of nonindustrial ownership and reflect an origin of both old-field and cutover woodland. Hardwoods occur in understory and midcanopy positions and consist of a typical mixture of upland species, such as sweetgum *(Liquidambar styraciflua)* and yellow poplar *(Liriodendrom tulipifera)*. Therefore, it is necessary to incorporate the proportion of hardwood basal area into a stand yield equation to explain the decrease in pine stand volume as hardwood basal area increases. This goal was initially accomplished by Shiver and Brister (1996).

After remeasurement in 1994, these researchers realized that, when the proportion of hardwood basal area is high, their models could give rise to biased projections. Therefore, using data gathered from the two measurements, Martin and Brister refit the models for survival rate, dominant height, and basal area for the variable hardwood components. In conjunction with the merchantable volume equations developed by Shiver and Brister (I 996), these models can now be used to obtain a distribution of projected stand yield into product classes in the presence of a wide range of dynamic hardwood competition. It is worth noting that, when they were remeasured in 1994, I6 of the 75 plots had been harvested during the five-year period, with 59 plots remaining. Based on table 1 of Martin and Brister (1999), we computed the mean values of pine trees per acre, their age and basal area, and percent of hardwood basal area as weighted averages of these 59 plots. With these mean values, the growth models fit by Martin and Brister allow us to configure the specific production process. Then, with the merchantable volume equations for sawtimber and pulpwood presented in Shiver and Brister (1996) yields for these output classes are obtained. Although the hardwood growth is used to predict softwood dynamics, the hardwood volume is not included.

Because ofgreater profit potential, trees are planted in lieu of natural regeneration on old-field lands. Hence it makes little sense to consider natural pine stands grown on old fields. Furthermore, for plantations established on old-field lands, site preparation is unnecessary. In fact, the only distinction between plantations of previous and current generations is whether or not vegetation is under effective control. Growth-and-yield models for these generations were developed based on sample measurements taken in 37 randomly chosen stands (Pienaar and Rheney 1997). Admittedly, these plantation models are developed from data covering less than a full rotation, and thus caution should be taken in interpreting results, although the latest field observations suggest they still fit well (PMRC 1999).

**Table 2. Characteristics of the five management regimes.**

| Characteristic | Natural stands | Plantations on cutover lands: Previous generation | Plantations on cutover lands: Current generation | Plantations on old-field lands: Previous generation | Plantations on old-field lands: Current generation |
|---|---|---|---|---|---|
| Model source | Martin and Brister (1999) | Chapter 3. Pienaar and Rheney (1997) | Chapter 3, Pienaar and Rheney (1997) | Chapter 4, Pienaar and Rheney (1997) | Chapter 4, Pienaar and Rheney (1997) |
| Stand origin | Natural | Artificial | Artificial | Artificial | Artificial |
| Initial density | Unknown | 600 trees at age 2 | 600 trees at age 2 | 600 trees at age 2 | 600 trees at age 2 |
| Weed control | None | Not effective | Effective | Not effective | Effective |
| Site preparation | None | Mechanical | Chemical | None | None |

**Table 3. Growth-and-yield summary of the five management regimes.**

| Age (year) | Number of stems | Height (feel) | Diameter (inches dbh) | Sawtimber (cords) | Pulpwood (cords) |
|---|---|---|---|---|---|
| **Natural stands** | | | | | |
| 15 | 303 | 35.47 | 3.13 | 0.00 | 0.74 |
| 20 | 273 | 48.67 | 4.79 | 0.03 | 6.51 |
| 25 | 247 | 58.84 | 6.26 | 3.05 | 11.01 |
| 30 | 224 | 66.77 | 7.56 | 11.66 | 10.45 |
| 35 | 203 | 73.09 | 8.73 | 21.57 | 8.46 |
| **Cutover site, previous-generation plantations** | | | | | |
| 15 | 512 | 43.11 | 6.00 | 1.03 | 18.05 |
| 20 | 460 | 53.08 | 7.05 | 8.60 | 22.60 |
| 25 | 409 | 61.99 | 7.99 | 20.59 | 20.49 |
| 30 | 362 | 70.04 | 8.88 | 32.34 | 16.51 |
| 35 | 321 | 77.36 | 9.74 | 42.10 | 12.78 |
| **Cutover site, current-generation plantations** | | | | | |
| 15 | 512 | 55.11 | 6.98 | 10.29 | 29.09 |
| 20 | 460 | 64.54 | 7.90 | 24.97 | 26.60 |
| 25 | 409 | 72.26 | 8.71 | 37.61 | 21.37 |
| 30 | 362 | 78.87 | 9.49 | 47.15 | 16.47 |
| 35 | 321 | 84.73 | 10.24 | 54.09 | 12.56 |
| **Old-field site, previous-generation plantations** | | | | | |
| 15 | 523 | 46.05 | 7.43 | 14.96 | 27.23 |
| 20 | 507 | 58.09 | 8.28 | 33.68 | 28.01 |
| 25 | 495 | 68.00 | 8.83 | 47.51 | 26.50 |
| 30 | 484 | 76.08 | 9.21 | 56.68 | 24.79 |
| 35 | 484 | 82.61 | 9.42 | 61.97 | 23.95 |
| **Old-field site, current-generation plantations** | | | | | |
| 15 | 523 | 55.79 | 8.47 | 44.48 | 31.80 |
| 20 | 507 | 66.65 | 9.01 | 59.52 | 29.33 |
| 25 | 495 | 75.06 | 9.35 | 66.96 | 26.88 |
| 30 | 484 | 81.66 | 9.58 | 70.62 | 24.86. |
| 35 | 484 | 86.91 | 9.68 | 71.77 | 23.94 |

The conventional measurement of site index for natural pine is the dominant tree height of rhe srand (in feet) at age 50. Shiver and Brisrer (1996) report a mean site index of 86, which corresponds to a sire index of 62 at age 25 for planted pine. Therefore, rhis sire index (62 feer) is used for the two cutover plantarion regimes. The lack of weed competition and the presence of residual fertility in old-field lands can boost the height growth by 6 to 7 feet at age 25 (Pienaar and Rheney 1997). Thus, we set rhe sire index of old-field plantation pine at 68. For planted pine, the number of stems at age 2 is commonly chosen to be 600 trees per acre (Pienaar and Rheney 1997). The total merchantable volume is defined as the volume wirh a diamerer at breast height (dbh) of 4 inches or greater, with a top of 2 inches or greater; sawtimber is defined as the volume with a dbh of 8 inches or greater, with a rop of 6 inches or greater. Pulpwood is the difference between total merchantable and sawrimber volume. A widely used volume conversion is one cord = 90 cubic feet of solid wood and bark (Norris Foundation 1999). To be conservative, however, we defined one cord as 95 cubic feet. Stand characteristics of the five different regimes are summarized in table 2, and the growth-and-yield models themselves are available from the primary author.

## Biological Productivity

The growth models suggest that the control of competing vegetation resulted in dramatic responses in dominant height and basal area growths, but its effect on the survival rate was inconsequential. For this reason, Pienaar and Rheney (1997) treated the number of stems in previous and current generarions of planted pine as the same. Understandably, naturally regenerated stands had a low survival rare-only 303 trees at age 15 and 203 at age 35 (*table 3*). And the small number of surviving trees may nor be well spaced-some were densely clustered, but others were sparsely distributed. Consequently, hardwood intrusion was inevitable, which in turn negatively affected rhe growth of pine trees. Trees planted on cutover lands were better spaced, but rhe constraints of soil nutrients and other factors led to strong competition and to a steady decline over time. The number of trees decreased from 600 at age 2 to 409 at age 25. In contrast, trees planted in old-field plantations had a very high survival rate-507

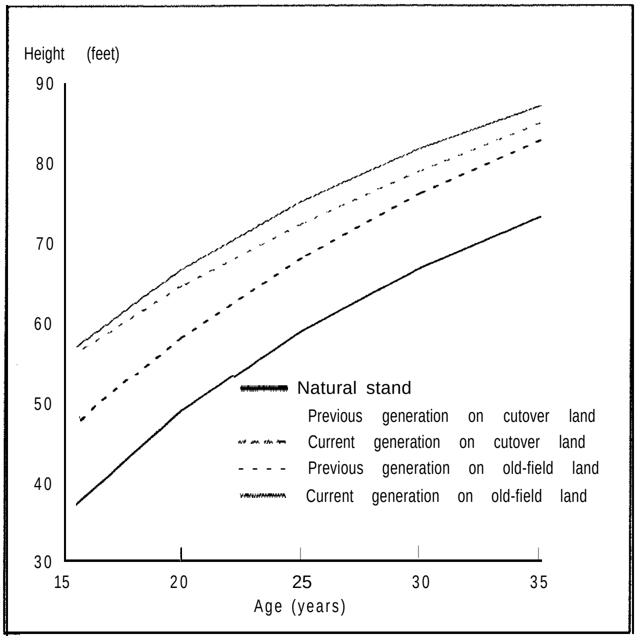


***Figure 1.*** **Height growth of loblolly pine under various management regimes.**

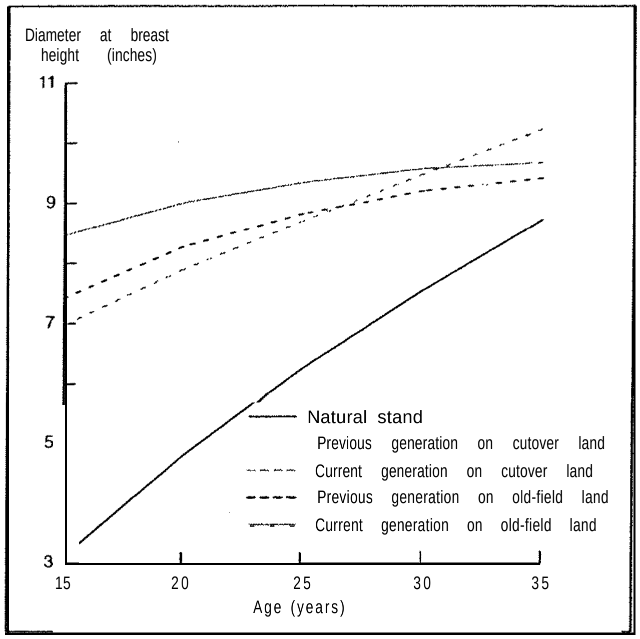


***Figure 2.*** **Diameter growth of loblolly pine under various management regimes.**

trees at age 20—because of residual fertility and thus more vigorous early growth.

Height growth of dominant trees was faster in plantations rhan in natural stands, and it was considerably greater in old-field plantations than in cutover ones. Similarly, the dominant height growth in current-generation plantations was greater than that implied by models developed for previous-generation plantations. *Figure* I shows that natural stands and previous- and current-generation plantations on cutover lands had a dominant height of 48.7, 53.1, and 64.5 feer, respectively, at age 20. In comparison, previous and current generations ofplantations on old-field lands had a dominant height of 58.1 and 66.7 feer, respectively, at age 20.

With regard to diameter growth, natural stands and plantations again exhibited different patterns. *Figure* 2 illustrates that, although natural stands grew very slowly in diameter, they maintained a steady increase over a long period of time. On the other hand, the diameter growth was fast in young plantations but leveled off quickly. This trend was more evidenr for old-field than cutover stands. Compared to a dbh of 4.8 inches for natural stands at age 20, previous- and current-generation plantations on cutover sites had a dbh of 7.1 and 7.9 inches, respectively. This increased to 8.3 and 9.0 inches in the old-field regimes. Clearly, the effect of herbaceous control on diameter growth was less significant rhan rhe effect of site quality and stand origin.

Variations in survival rate and height and basal area growth resulted in different yields among the five regimes examined. For instance, at age 20 a narural stand was expected to produce only 6.5 cords of pulpwood, whereas a previous-generation plantation on cutover land would yield 22.6 cords ofpulpwood and 8.6 cords ofsawtimber *(table 3)*. These figures jumped to 26.6 and 25.0 cords, respectively, for a current-generation plantarion on cutover land. If the plantation is established on old-field land, its yield at age 20 was expected to increase to 28.0 cords of pulpwood and 33.7 cords of sawtimber for the previous generation and 29.3 cords of pulpwood and 59.5 cords of sawtimber for the current generation. Therefore, when stands were close to or older than 20 years, various plantation regimes resulted in a similar amount of pulpwood, with almost all the volume increase due to the regime shift in the more valuable sawtimber class.

To summarize, between plantations and natural stands, plantations resulted in faster growth and higher yield; between previous- and current-generation plantations, weed control by herbicide application led to substantial volume increase in the current generation; and between plantations established on cutover and old-field lands, the latter demonstrated much greater growth and yield. Regardless of the specific plantation regime, however, most of the increased volume showed up in the sawrimber class.

## Economic Performance

We use the profit function for timber production suggested by Yin and Newman (I 997):

$$\pi_t(p_t, i_t, w_t, r_t) = max\,\{p_t f(t) - i_t p_t I(t) - w_t K(t) - r_t L(t)\}$$

where $\pi_t$ is net revenue at time $t$, $p_t$ is srumpage price, $f(t)$ is harvest volume, $w_t$ is regeneration cost, $r_t$ is land rental cost, $i_t$ is discount rate, $I(t)$ is stocking volume, $K(t)$ is operating input, and $L(t)$ is land acreage. This function captures rhe continuous nature and revelation of the cost components of timber production. In addition, this function can deal with multiple operating inputs and multiple outputs easily. Because of this, Yin and Newman (1997) referred to it as a forest-level model, as compared to the Faustmann ([1849]

1995) stand-level model.

Taken from *Ember-Mart* South (Norris Foundation 1999), the stumpage prices used in our analysis reflect average levels occurring in the mid-1990s in Georgia's Piedmont. They are $29 per cord for pulpwood and $94 per cord for sawtimber. Cost figures are set in reference to those for forestry practices in the same region during the same period (Dubois et al. 1997). *Table* 4 presents price and cost parameters. To obtain land productivity and production costs and profits, one more unit of land must be added co the calculation because of the lag caused by site preparation before regeneration; e.g., for a rotation age of 20 years, 21 units of land will be needed.

***Tabfe.5*** uses the natural stand regime as an example co detail how the optimal rotation age is determined. First, we calculate total revenues and total costs for different rotation ages. Next, the optimal rotation age is determined when the net revenue, or the difference between total revenue and total cost, is maximized. Given the involved growth process and price and cost parameters in this case, the maximum net revenue ($552.31) is reached when the rotation age is 36, implying a 36-year optimal rotation age. Once the rotation age is determined, we can calculate the corresponding outputs (8.1 cords of pulpwood and 23.5 cords of sawtimber), land productivity (0.9 cord per acre per year), and net revenue ($14.80 per acre per year). We can also derive the internal rate of return by increasing the discount race until total revenue equals total cost, or the net revenue becomes zero. For natural stands, this internal rate of return is 7.92 percent.

***Table** 6* (p. 16) summarizes our calculated results for all five regimes. The table shows that intensified regimes tend co push the optimal rotation age downward but productivity, and thus profitability, upward. Relative to natural stands, the rotation age of previous-generation plantations on cutover lands decreases co 27 years, while their annual outputs increase co 18.9 cords of pulpwood and 25.5 cords of sawtimber. This translates into a productivity of 1.6 cords and a subsequent profit of $23.79 per acre per year. The associated internal race of return is 8.05 percent. For current-generation plantations with a rotation age of 21 years, the outputs increase co 25.6 cords of pulpwood and 27.7 cords of sawtimber, resulting in a productivity of 2.4 cords and a profit of $51.38 per acre per year. As a result, the internal rate increases co 9.62 percent.

Our results for old-field plantations are more impressive. With a rotation age of 21 years, the same as the current-generation plantations on cutover lands, previous-generation plantations substantially increase the sawtimber output, yielding a productivity of 2.9 cords and a profitability of $85.80 per acre per year. The current generation has the capacity co produce 31.4 cords of pulpwood and 48.4 cords of sawtimber with a rotation age of only 16 years. Consequently, productivity and profitability are very high-4.7 cords and $173.40 per acre per year.

Alternatively, we can compare the unit production costs. Assuming the cost ratio between sawtimber and pulpwood is the same as their price ratio, we find that, under natural regeneration, production costs are $22.66 per cord for pulpwood and $73.43 per cord for sawtimber. Compared to natural stands, previous-generation plantations on cutover lands show little decrease in production costs, whereas the current

**Table 4. Average cost and price information for various pine management practices, Georgia Piedmont, late-l 990s.**

| | |
|---|---|
| Chopping | $102.50 per acre |
| Burning | $20 per acre |
| Herbicide use | $158 per acre |
| Seedling | $33.60 per acre |
| Planting | $42.70 per acre |
| Discount rate | 6 percent |
| Cutover land price | $300 per acre |
| Old-field land price | $350 per acre |
| Overhead | $2 per acre per year |
| *Ad valorem* tax | $2.50 per acre per year |
| Sawtimber price | $94 per cord |
| Pulpwood price | $29 per cord |

*Source:* *Dubois et al. (1997); Norris Foundation (1999).*

**Table 5. Optimal rotation determination for natural loblolly stands.**

| | Revenue | | | cost | | | | |
|---|---|---|---|---|---|---|---|---|
| Age | Pulpwood | Sawtimber | Total | Capilal | Land | Operating | Total | Net revenue |
| 31 | $ 292.24 | $ 1,282.42 | $ 1,574.66 | $ 450.21 | $ 558.00 | $ 139.50 | $ 1.147.71 | $ 426.94 |
| 32 | 280.74 | 1,470.11 | 1,750.85 | 555.27 | 576.00 | 144.00 | 1,275.27 | 475.59 |
| 33 | 268.92 | 1,657.62 | 1,926.53 | 670.86 | 594.00 | 148.50 | 1.413.36 | 513.18 |
| 34 | 257.06 | 1,843.69 | 2,100.75 | 796.90 | 612.00 | 153.00 | 1,561.90 | 538.85 |
| 35 | 245.38 | 2,027.41 | 2.272.79 | 933.27 | 630.00 | 157.50 | 1,720.77 | 552.02 |
| 36 | 234.01 | 2,208.10 | 2,442.11 | 1,079.80 | 648.00 | 162.00 | 1,889.80 | 552.31 |
| 37 | 223.04 | 2,385.27 | 2,608.31 | 1,236.30 | 666.00 | 166.50 | 2,068.80 | 539.51 |
| 38 | 212.52 | 2,558.58 | 2,771.10 | 1,402.56 | 684.00 | 171 .oo | 2,257.56 | 513.54 |
| 39 | 202.48 | 2,727.79 | 2,930.27 | 1.578.38 | 702.00 | 175.50 | 2,455.88 | 474.40 |
| 40 | 192.94 | 2,892.73 | 3,085.67 | 1.763.52 | 720.00 | 180.00 | 2,663.52 | 422.15 |

**Table 6. Economic summary of the five loblolly pine management regimes in Georgia's Piedmont.**

| Regime | Rotation (year) | Output: Pulpwood (cords per acre) | Output: Sawlimber (cords per acre) | Productivity (cords per acre per year) | Profitability ($ per acre per year) | Cost: Pulpwood ($ per cord) | Cost: Sawtimber ($ per cord) |
|---|---|---|---|---|---|---|---|
| Natural stands | 36 | 8.07 | 23.49 | 0.88 | $14.84 | $22.66 | $73.43 |
| Cutover land, previous-generation plantations | 27 | 18.95 | 25.47 | 1.59 | 23.79 | 22.44 | 72.73 |
| Cutover land, current-generation plantations | 21 | 25.62 | 27.74 | 2.43 | 51.38 | 19.22 | 62.29 |
| Old-field land, previous-generation plantations | 21 | 27.79 | 36.86 | 2.94 | 85.81 | 16.18 | 52.45 |
| Old-field land, current-generalion plantations | 16 | 31.38 | 48.39 | 4.69 | 173.40 | 13.34 | 43.24 |

generation results in a cost reduction of more than 16 percent to $19.22 per cord for pulpwood and $62.23 per cord for sawtimber. Comparatively, increased volume for the previous generation mostly goes to pulpwood, an output with low value, while various practices associated with the plantation establishment add to production costs. For previous-generation plantations on old-field lands, however, these costs are reduced to $16.18 per cord for pulpwood and $52.45 per cord for sawtimber; for the current generation, they are $13.34 per cord and $43.24 per cord, respectively. If these figures for current-generation old-field planrations seem too optimistic, even if we compare natural stands with previous-generation plantations on old-field lands or treat all the timber produced from current-generation plantations as pulpwood, we still find that production costs can be reduced by as much as 40 percent.

## Conclusions and Implications

We found that productivity of previous-generation plantations of loblolly pine established on cutover lands is significantly higher than that of natural stands; however, profitability improves slightly while production costs remain virtually the same. In contrast, current generation-plantations can boost profits and reduce costs of timber production dramatically. Furthermore, previous-generation plantations established on old-field lands substantially ourperform the current-generation plantations established on cutover lands, and current-generation plantations on old-field lands can perform even better.

Our results indicate that the marginal returns of forest management are increasing rather than diminishing; the more intensive the management, the better its economic performance. Given growrh-and-yield potentials and market conditions, landowners can greatly enhance timber productivity and profitability by intensifying their management. Therefore, intensive management represents a major change in silvicultural technology. To pursue this opportunity, however, government and business organizations must focus more on education, research, and technology of plantation management (Binkley 1999).

As for specific silvicultural treatments, it is clear that given improved planting stock, the control of competing vegetation using herbicides is the most important practice in plantation management, followed by fertilization and thinning. Together these practices may increase yields on cutover lands to a level nearly as high as yields on old-field lands. Given the limited availability of old-field lands and the possibility of reduced productivity in later rotations, it is especially important to intensify the management of plantations on cutover sites using fertilizers and competition control. Borders and Bailey (2001) report that complete vegetation control and multiple fertilizations on cutover land can result in an average yield of 50 cords per acre at age 14, or 3.5 cords per acre per year. A similar finding is also documented in Clutter (1995). In our results, the productivity of plantations on old-field lands ranges from 2.9 (previous generation) to 4.7 cords (current generation) per acre per year. As these numbers are among the best known worldwide, we can reasonably expect that stand growth-and-yield rates and thus cost-competitiveness of timber production in the South may well rival those for southern pine grown in other countries under intensive silvicultural practices.

From examining the cost structure of various management regimes, we see that by increasing the growth rate, more intensive management will lead to a greater stocking volume on a smaller land base. As such, operating and capital costs will increase but the cost of land will decrease. At an optimal rotation age of 36 years, the capital cost of natural stands accounts for 57 percent of total costs, whereas the land and operating costs are 34 percent and 9 percent 5). For previous-generation plantations on cutover lands, the operating and capital costs increase to 14 percent and 64 percent, while the land cost declines to 22 percent. For the current generation, the operating and capital costs increase further to 16 percent and 66 percent, while the land cost decreases to 18 percent. Thus, intensive forest management can be viewed as a process of using human input to boost timber production on a reduced land base.

Related to the high timber productivity is the opportunity to sequester carbon using intensively managed forests

(Johnsen et al. 2001). Compared to other management systems, intensive plantation forestry offers a very promising option in this regard. Still, some oppose plantation forestry because of its potential adverse effects on the environment, including reduced biodiversity and the likelihood of nutrient depletion in soil over rotations. Although these concerns are reasonable, all management strategies involve tradeoffs. Although intensive pine plantations feature a low degree of biodiversity in terms of ecosystem type and species composition, timber productivity is such that society's wood requirements can be met on a limited amount of land. In the Georgia Piedmont region, if timber were produced from the current generation of pine plantations grown on old-field lands instead of natural stands, the amount of land used would be reduced to less than 20 percent. As a result, more natural stands with their higher degree of biodiversity could be freed up from the pressures of timber harvests and devoted to other uses, including recreation, aesthetics, habitant protection, and wildlife conservation.

As to the possibility of depleting soil productivity due to intensive management, Allen (in press), Borders and Bailey (2001), and others have provided evidence that multiple fertilizations in a plantation rotation can at least maintain the soil productivity. And our analysis indicates that as long as high productivity can be maintained through fertilization, intensive management remains a cost-effective means of timber production. It should also be noted that, even in the most intensive use of fertilizers in forestry, its annual intensity is much lower than that for agricultural crops. Therefore, we are confident that with further research into issues related to the mechanisms of fertilization and retention of available soil nutrients, a healthy soil condition can be sustained.

Finally, because this work is based on the case of loblolly pine grown in the Georgia Piedmont, our results and conclusions should be understood in the appropriate context. The focus of this work is the economic performance of pine management regimes. We trust that future research will quantify the performance of these regimes in terms of physiology, ecology, and other aspects.

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